S 03 P1362

FIG. 1

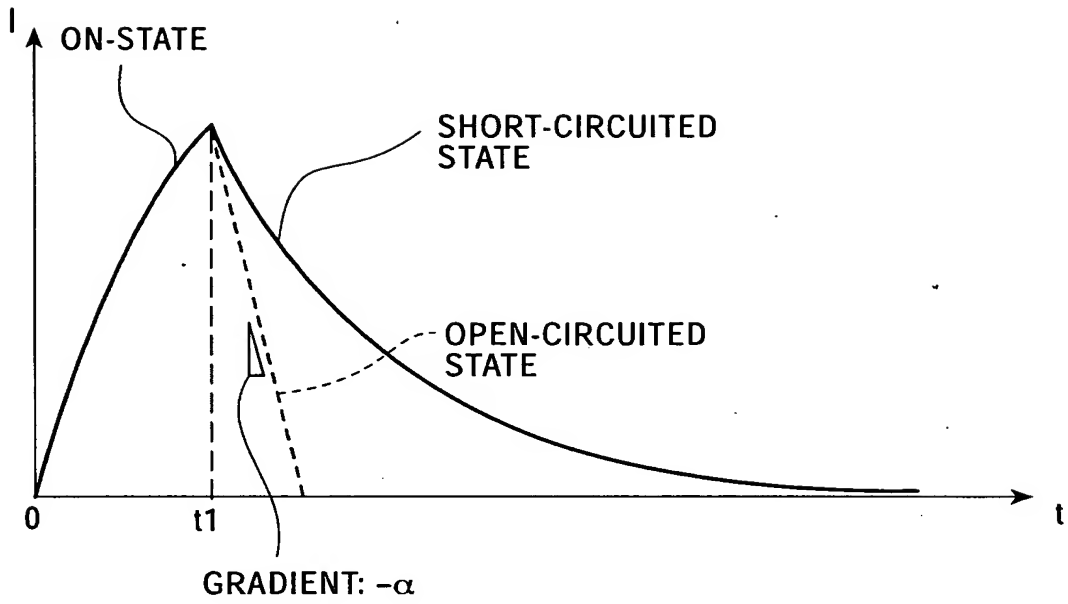


FIG. 2

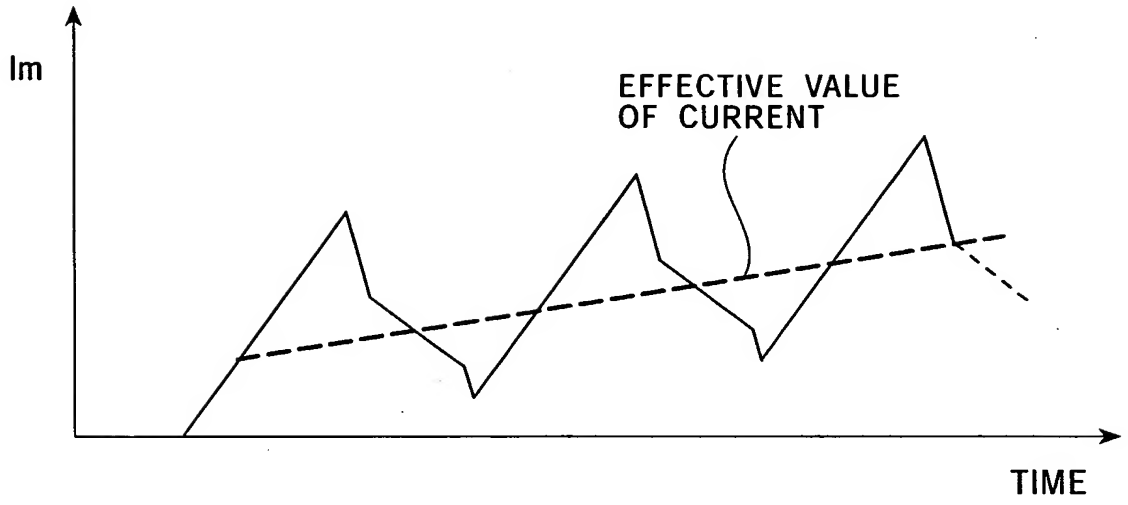

Im
EFFECTIVE VALUE
OF CURRENT
TIME

FIG. 3

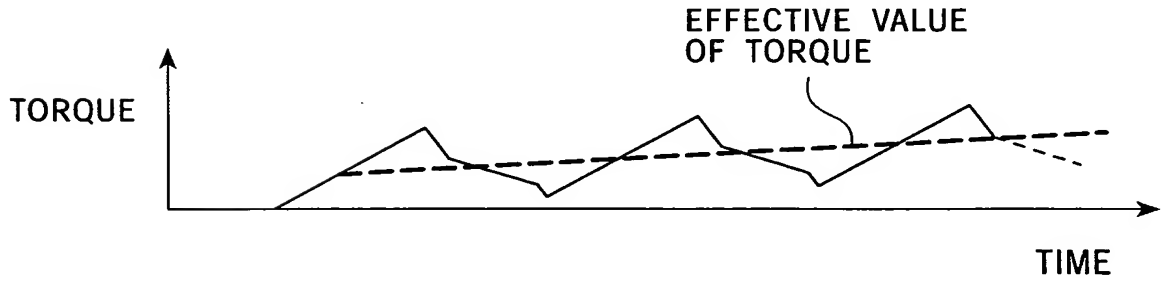

EFFECTIVE VALUE
OF TORQUE
TORQUE
TIME

FIG. 4

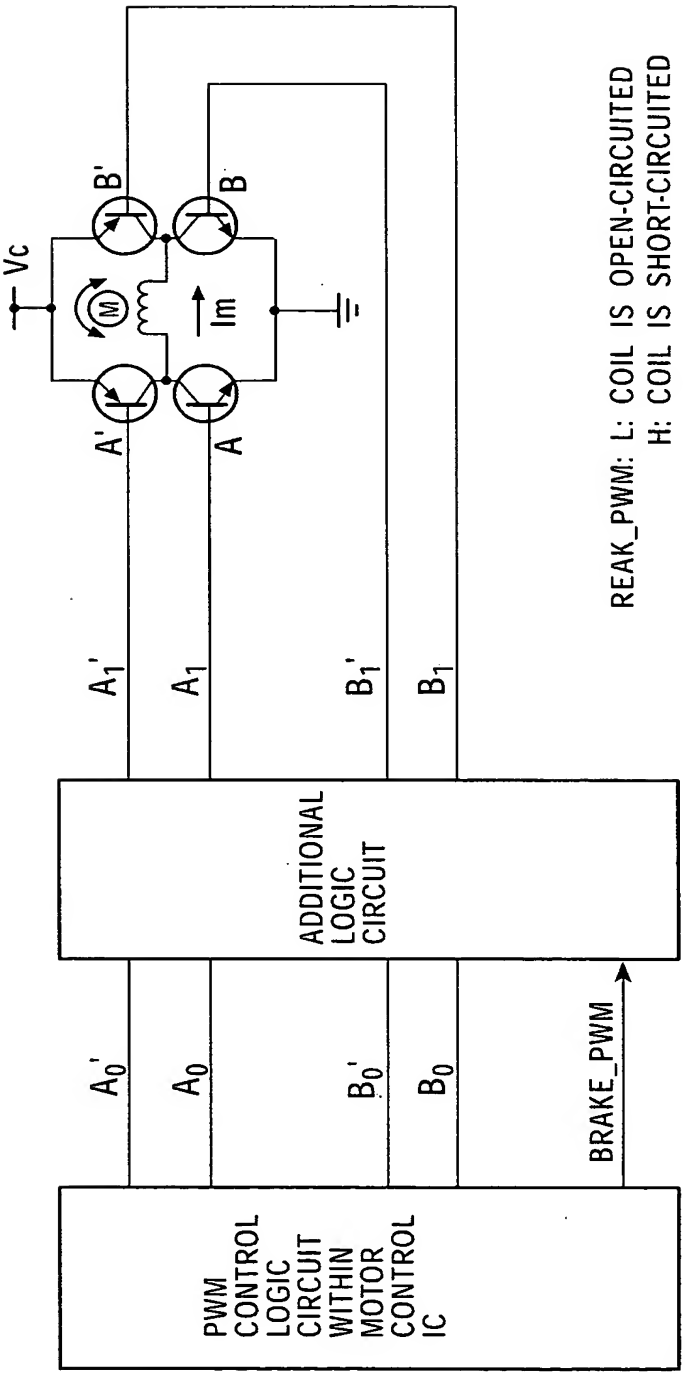

Vc
B'
B
M
Im
A'
A
A1'
A1
B1'
B1
ADDITIONAL LOGIC CIRCUIT
A0'
A0
B0'
B0
BRAKE_PWM
PWM CONTROL LOGIC CIRCUIT WITHIN MOTOR CONTROL IC
REAK_PWM: L: COIL IS OPEN-CIRCUITED
H: COIL IS SHORT-CIRCUITED

FIG. 5

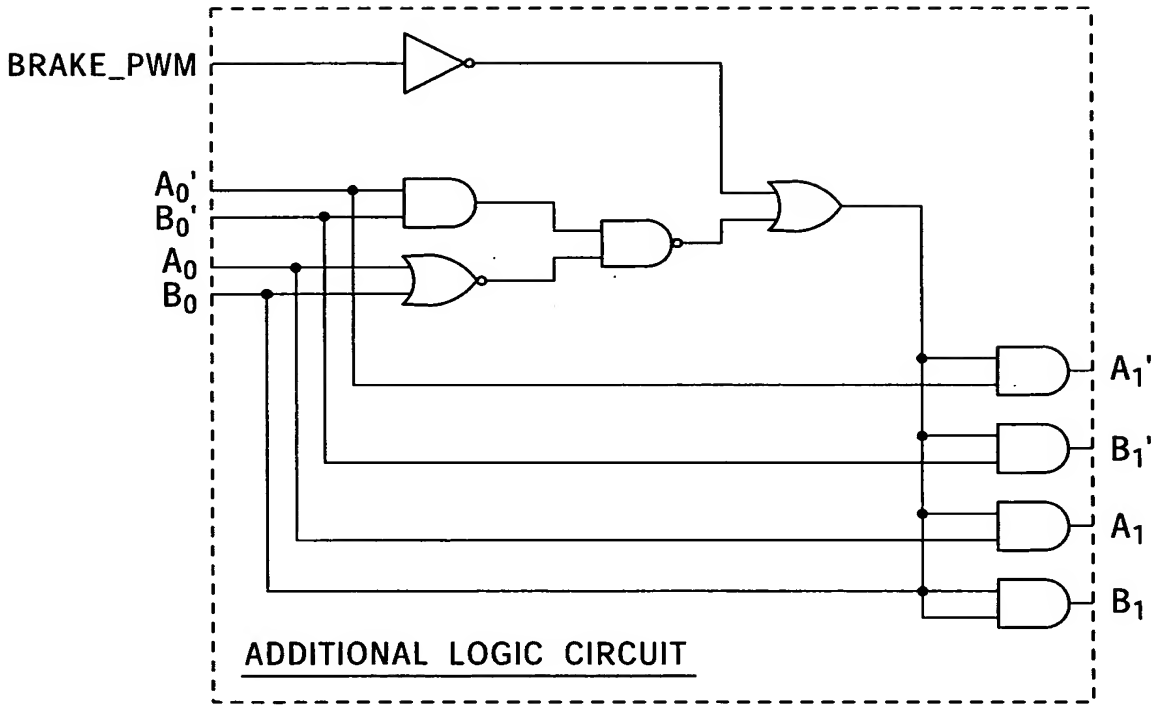


FIG. 6

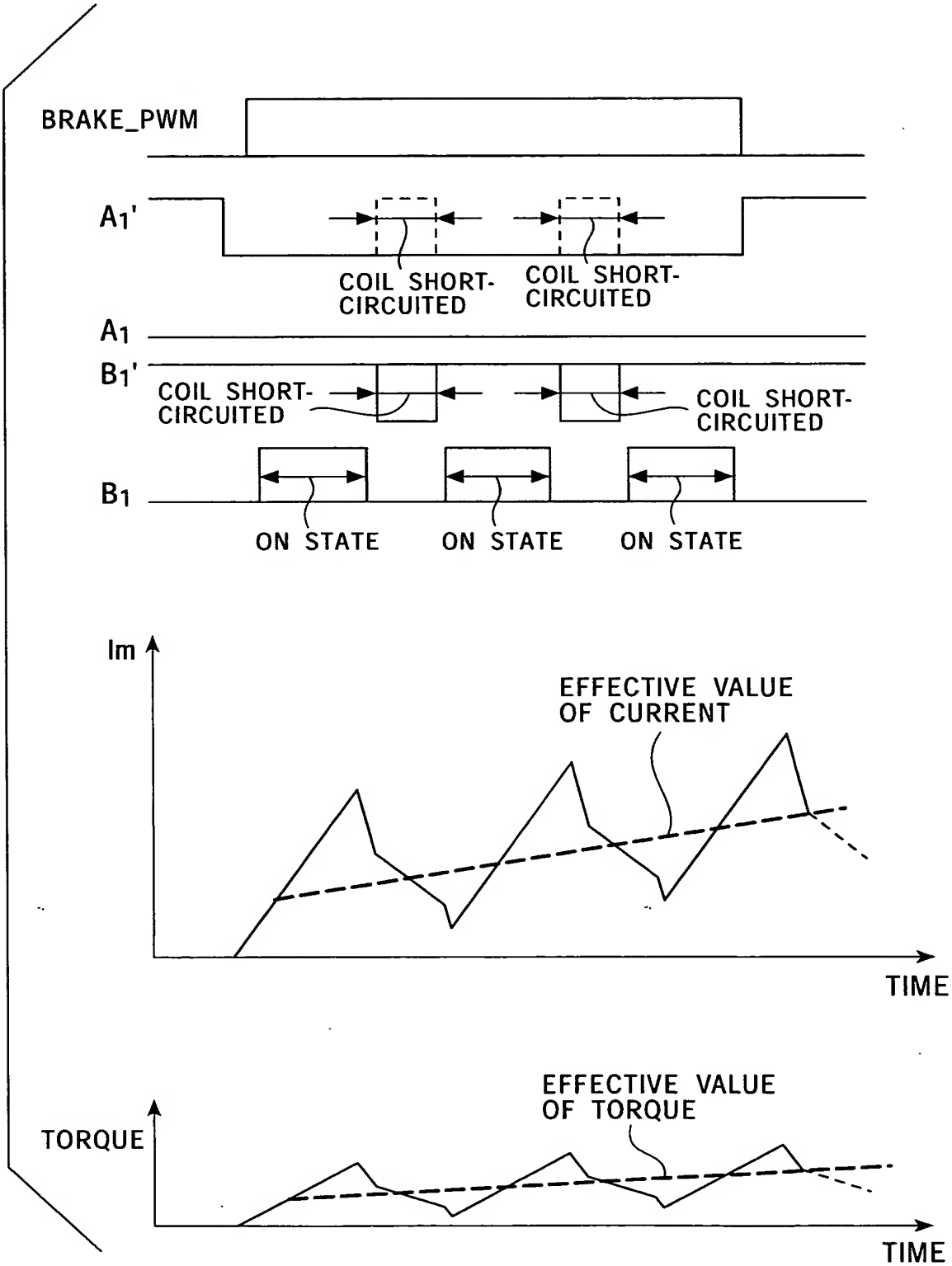

BRAKE_PWM
A1'
COIL SHORT-CIRCUITED
COIL SHORT-CIRCUITED
A1
B1'
COIL SHORT-CIRCUITED
COIL SHORT-CIRCUITED
B1
ON STATE
ON STATE
ON STATE
Im
EFFECTIVE VALUE OF CURRENT
TIME
TORQUE
EFFECTIVE VALUE OF TORQUE
TIME

FIG. 7

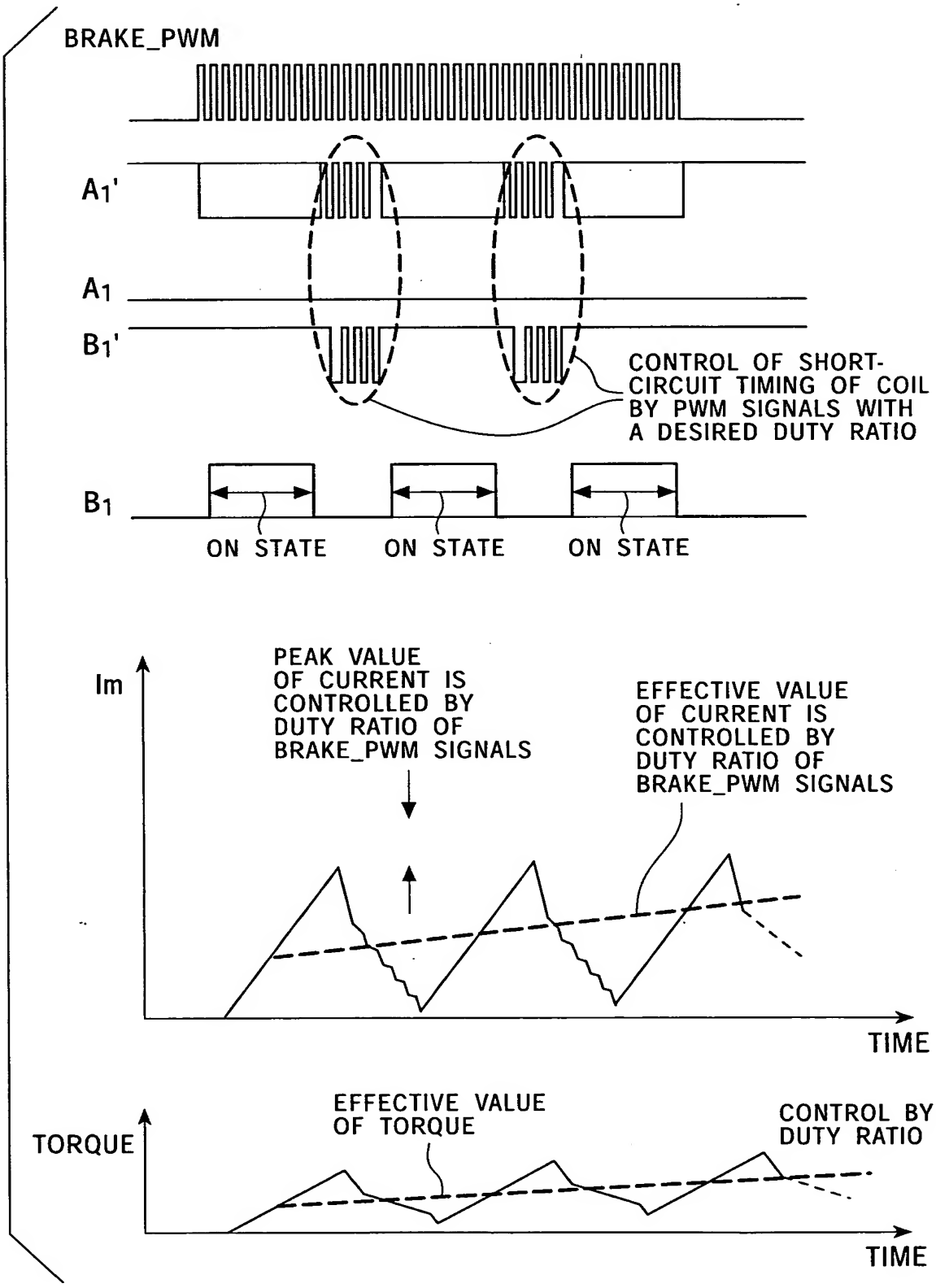

BRAKE_PWM
A1'
A1
B1'
CONTROL OF SHORT-CIRCUIT TIMING OF COIL BY PWM SIGNALS WITH A DESIRED DUTY RATIO
B1
ON STATE
ON STATE
ON STATE
Im
PEAK VALUE OF CURRENT IS CONTROLLED BY DUTY RATIO OF BRAKE_PWM SIGNALS
EFFECTIVE VALUE OF CURRENT IS CONTROLLED BY DUTY RATIO OF BRAKE_PWM SIGNALS
TIME
TORQUE
EFFECTIVE VALUE OF TORQUE
CONTROL BY DUTY RATIO
TIME

FIG. 8

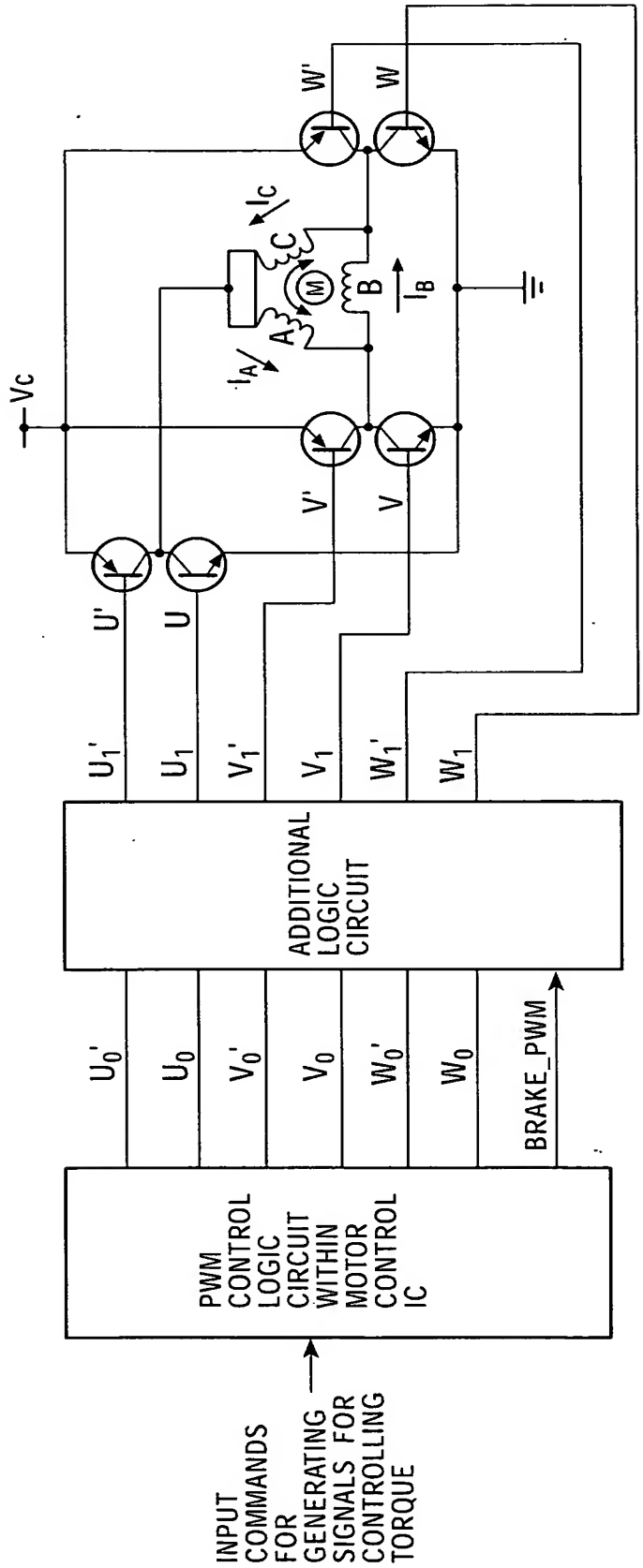
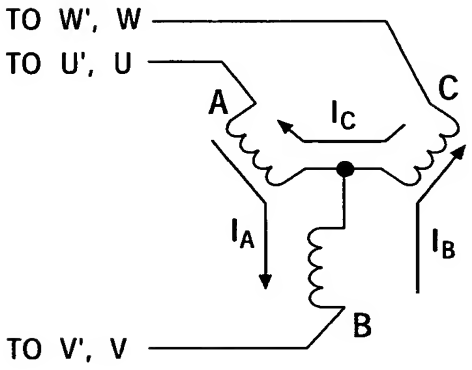

W'
W
Ic
C
M
B
IB
A
IA
Vc
V'
V
U'
U
U1'
U1
V1'
V1
W1'
W1
ADDITIONAL LOGIC CIRCUIT
U0'
U0
V0'
V0
W0'
W0
BRAKE_PWM
PWM CONTROL LOGIC CIRCUIT WITHIN MOTOR CONTROL IC
INPUT COMMANDS FOR GENERATING SIGNALS FOR CONTROLLING TORQUE

FIG. 9



I_A – I_C: CURRENTS FLOWING A-PHASE MOTOR COIL THROUGH C-PHASE MOTOR COIL (A)

R_A – R_C: DC RESISTANCES OF A-PHASE MOTOR COIL THROUGH C-PHASE MOTOR COIL (Ω)

L_A – L_C: INDUCTANCES OF A-PHASE MOTOR COIL THROUGH C-PHASE MOTOR COIL (H)

Vc: POWER SUPPLY VOLTAGE FOR DRIVING MOTOR (V)

Kt: TORQUE COEFFICIENT OF MOTOR (N-m/A)

Ka: COUNTER-ELECTROMOTIVE VOLTAGE COEFFICIENT OF MOTOR (V/rad/s)

FIG. 10

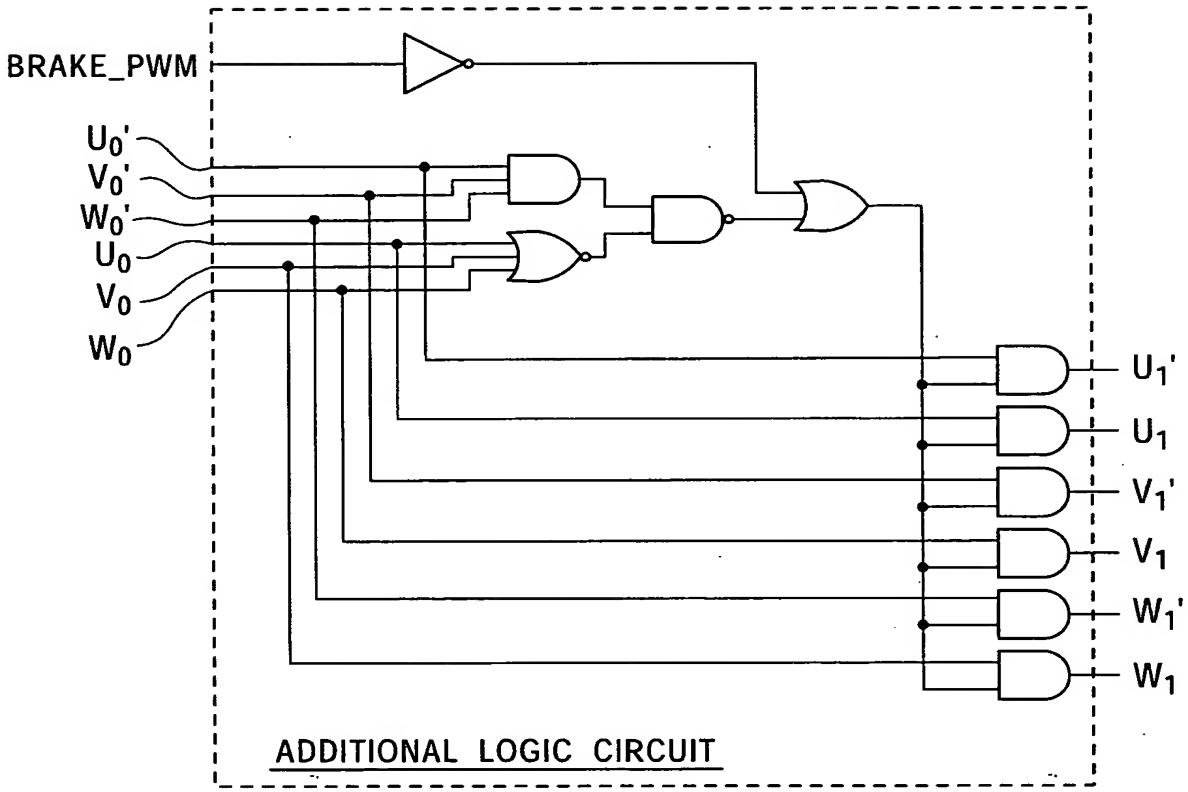

BRAKE_PWM
U0'
V0'
W0'
U0
V0
W0
U1'
U1
V1'
V1
W1'
W1
ADDITIONAL LOGIC CIRCUIT

FIG. 11

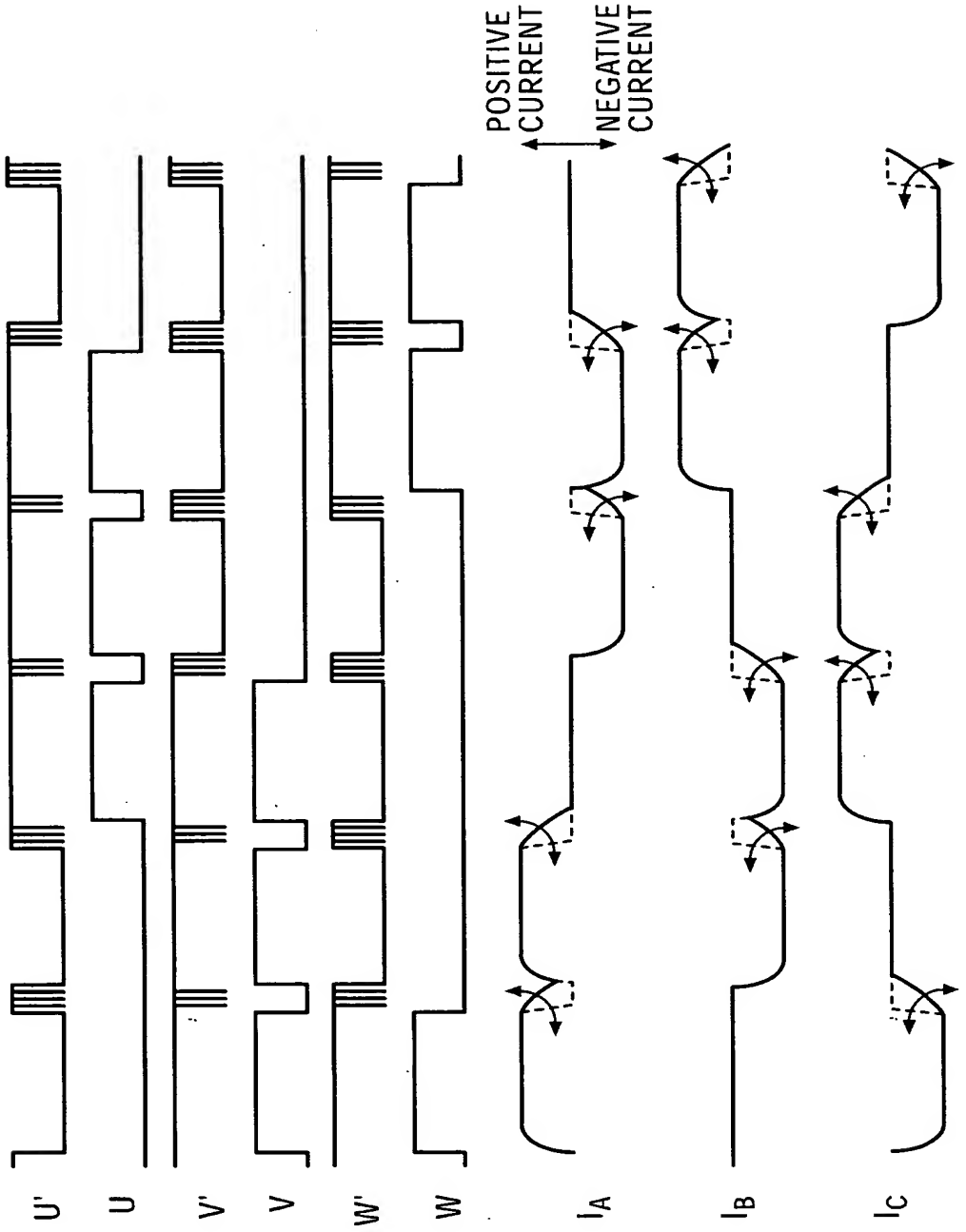


FIG. 12

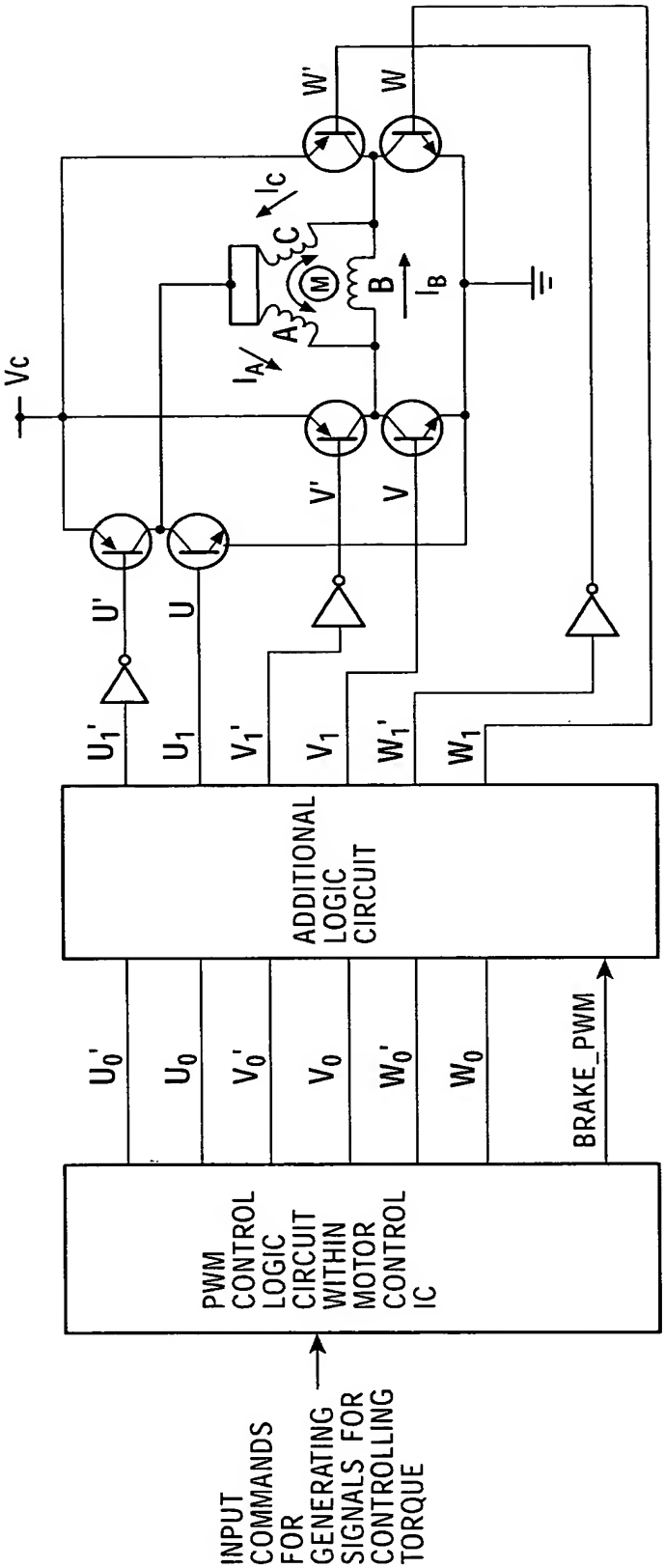

W'
W
Ic
C
M
B
IB
A
IA
Vc
V'
V
U'
U
U1'
U1
V1'
V1
W1'
W1
ADDITIONAL LOGIC CIRCUIT
U0'
U0
V0'
V0
W0'
W0
BRAKE_PWM
PWM CONTROL LOGIC CIRCUIT WITHIN MOTOR CONTROL IC
INPUT COMMANDS FOR GENERATING SIGNALS FOR CONTROLLING TORQUE

FIG. 13

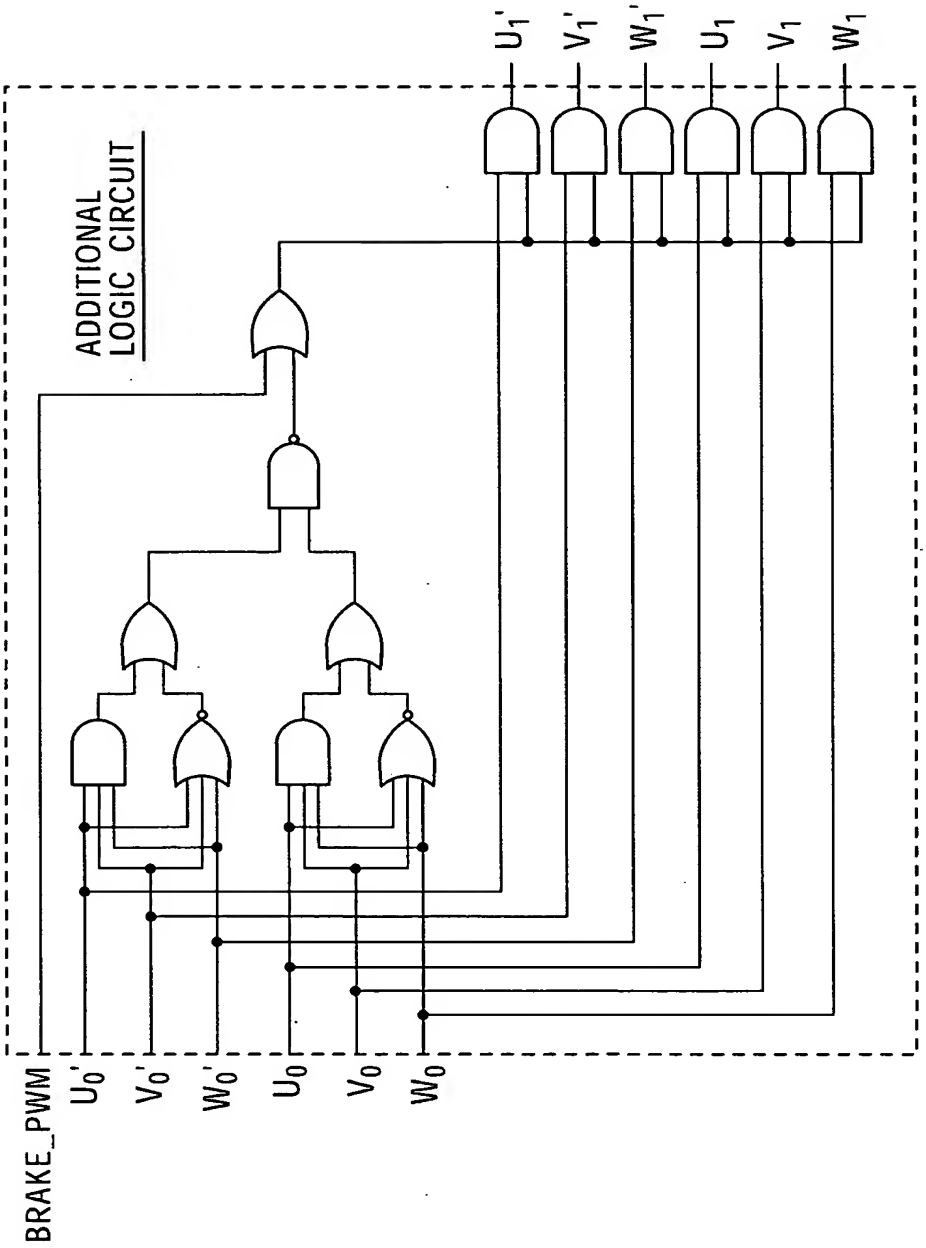

ADDITIONAL
LOGIC CIRCUIT
U1'
V1'
W1'
U1
V1
W1
BRAKE_PWM
U0'
V0'
W0'
U0
V0
W0

FIG. 14

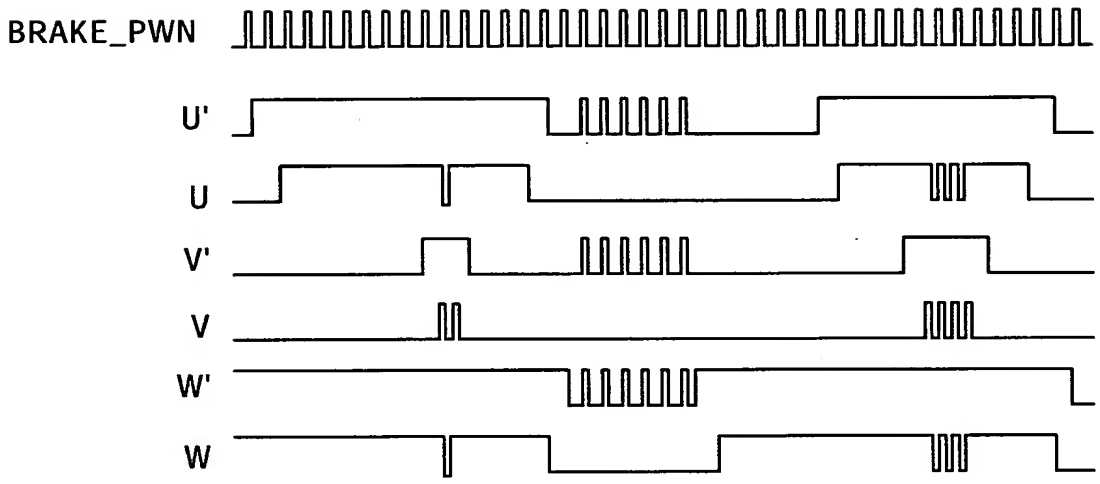


FIG. 15

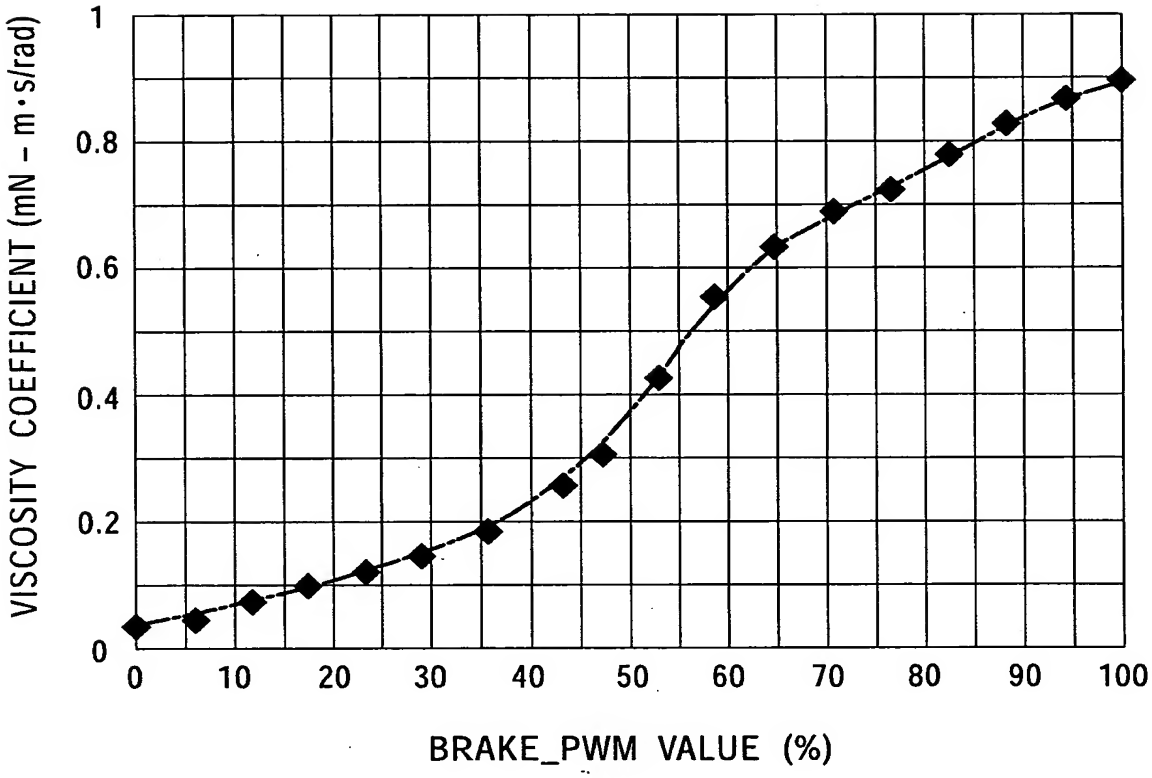

VISCOSITY COEFFICIENT (mN - m·s/rad)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
100
BRAKE_PWM VALUE (%)

FIG. 16

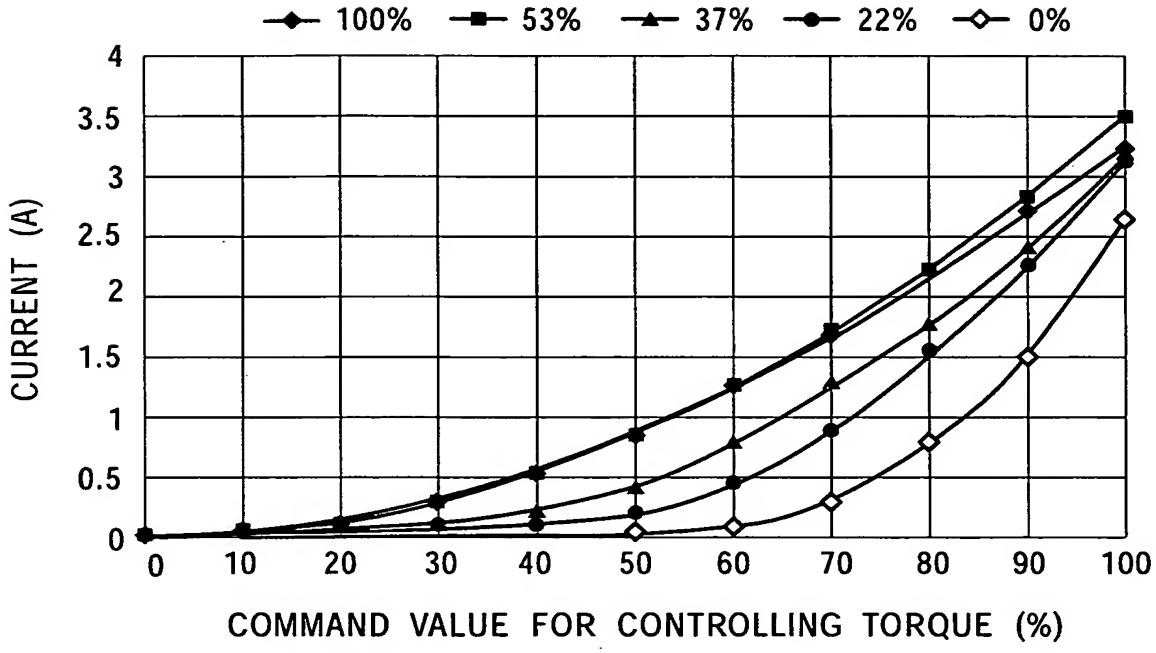

100%
53%
37%
22%
0%
CURRENT (A)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
70
80
90
100
COMMAND VALUE FOR CONTROLLING TORQUE (%)

FIG. 17

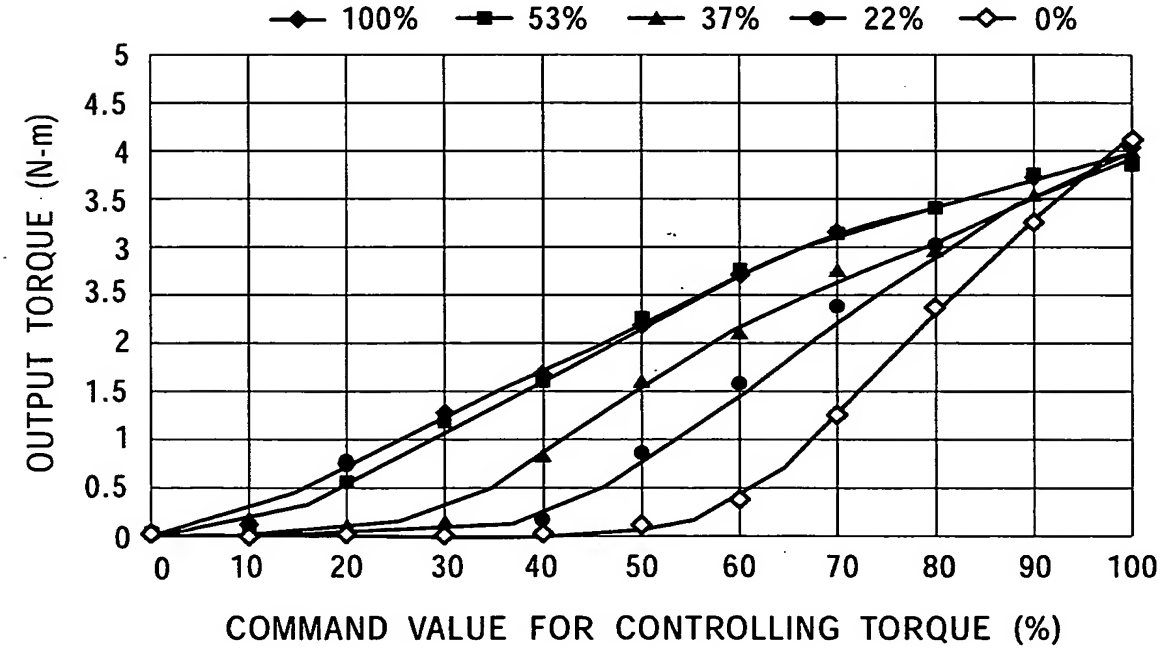

100%
53%
37%
22%
0%
OUTPUT TORQUE (N-m)
0
0.5
1
1.5
2
3
3.5
3.5
4
4.5
5
0
10
20
30
40
50
60
70
80
90
100
COMMAND VALUE FOR CONTROLLING TORQUE (%)

FIG. 18

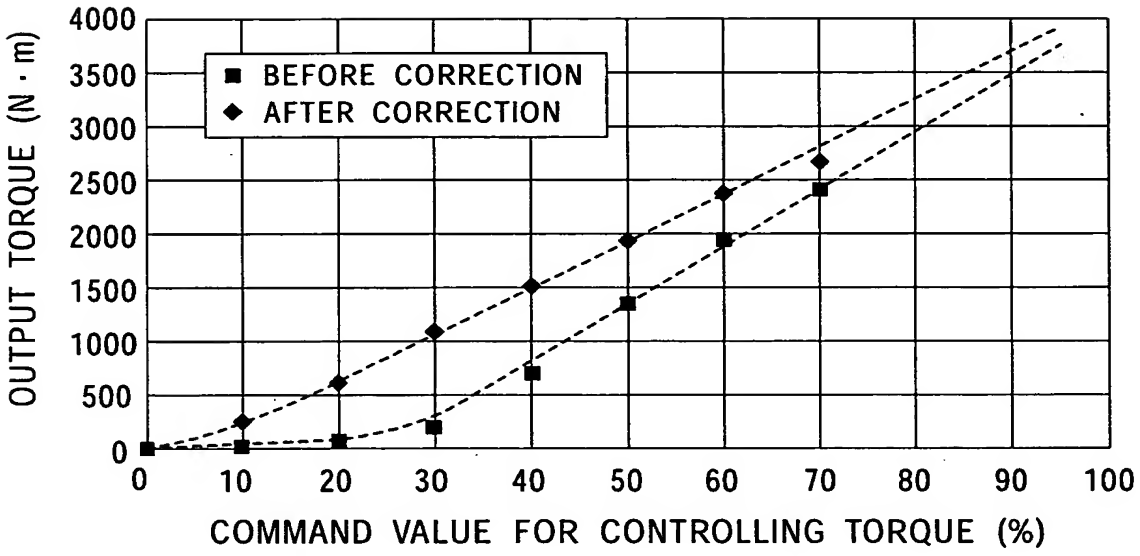

OUTPUT TORQUE (N · m)
4000
3500
3000
2500
2000
1500
1000
500
0
BEFORE CORRECTION
AFTER CORRECTION
0
10
20
30
40
50
60
70
80
90
100
COMMAND VALUE FOR CONTROLLING TORQUE (%)

FIG. 19

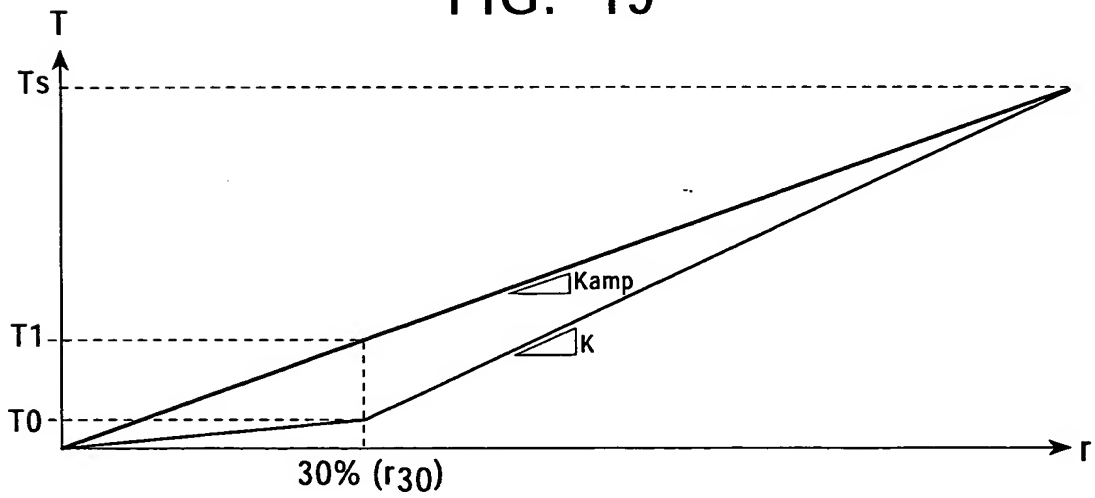

T
Ts
T1
T0
Kamp
K
r
30% (r30)

FIG. 20

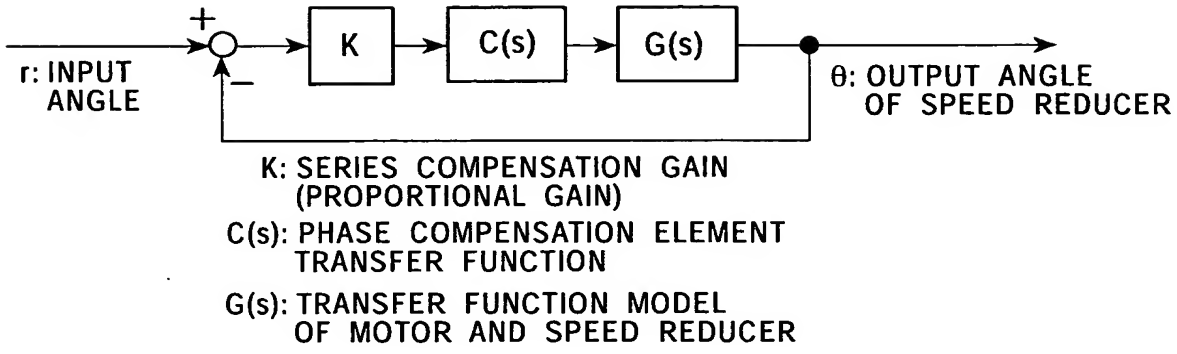

+
−
K
C(s)
G(s)
r: INPUT ANGLE
θ: OUTPUT ANGLE OF SPEED REDUCER
K: SERIES COMPENSATION GAIN (PROPORTIONAL GAIN)
C(s): PHASE COMPENSATION ELEMENT TRANSFER FUNCTION
G(s): TRANSFER FUNCTION MODEL OF MOTOR AND SPEED REDUCER

FIG. 21

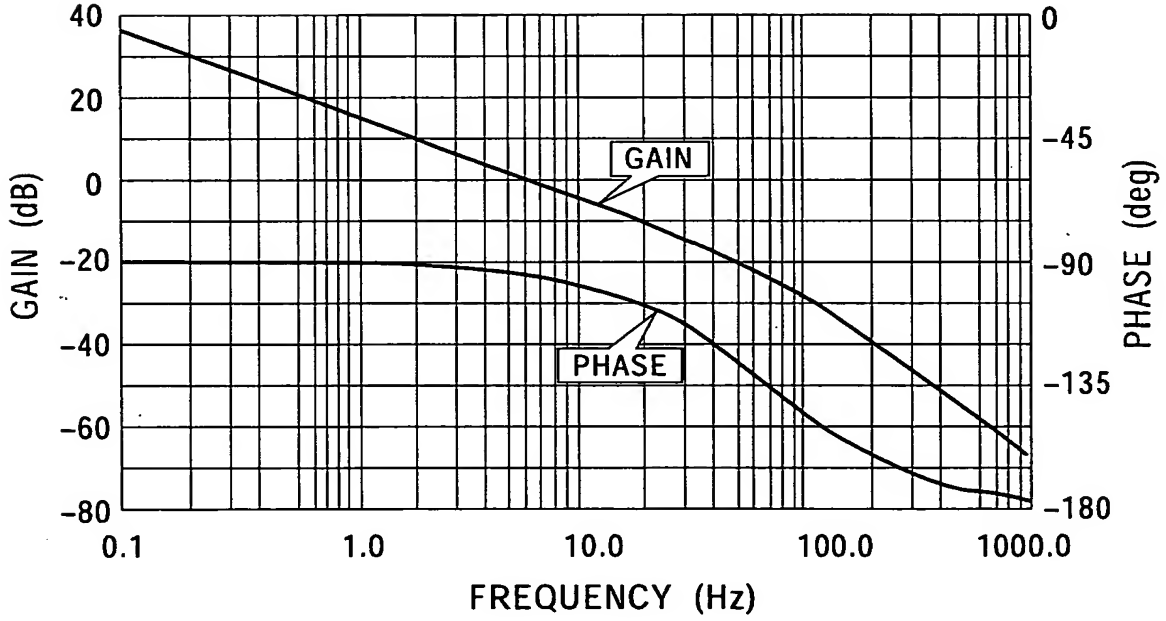

40
20
0
−20
−40
−60
−80
GAIN (dB)
0
−45
−90
−135
−180
PHASE (deg)
GAIN
PHASE
0.1
1.0
10.0
100.0
1000.0
FREQUENCY (Hz)

FIG. 22

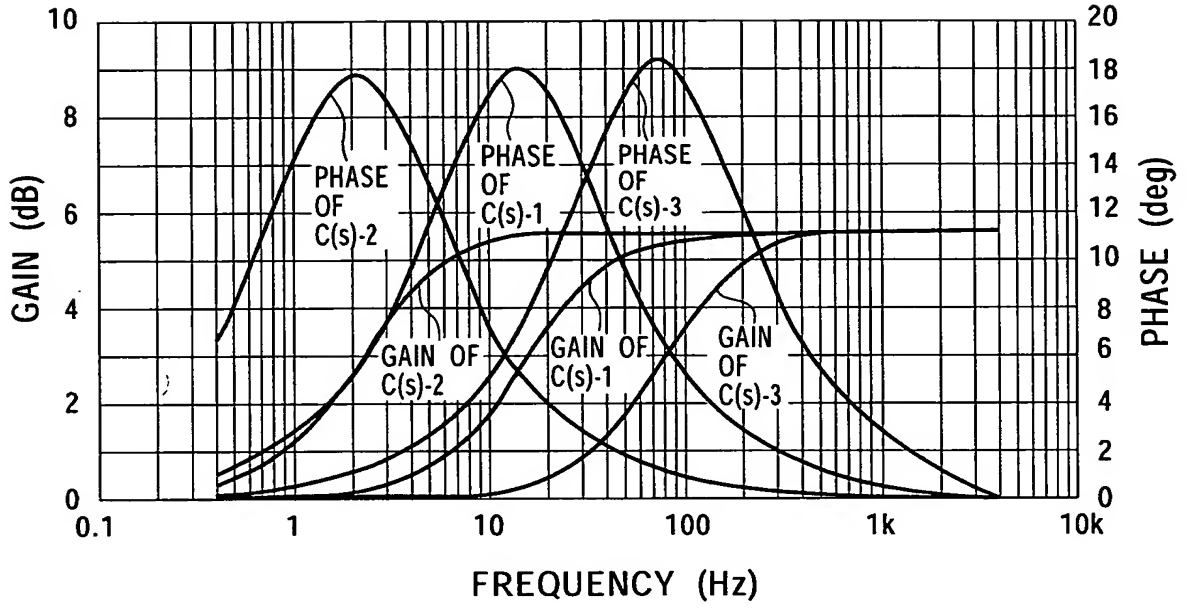

GAIN (dB)
PHASE (deg)
FREQUENCY (Hz)
PHASE OF C(s)-2
PHASE OF C(s)-1
PHASE OF C(s)-3
GAIN OF C(s)-2
GAIN OF C(s)-1
GAIN OF C(s)-3
0.1
1
10
100
1k
10k

FIG. 23

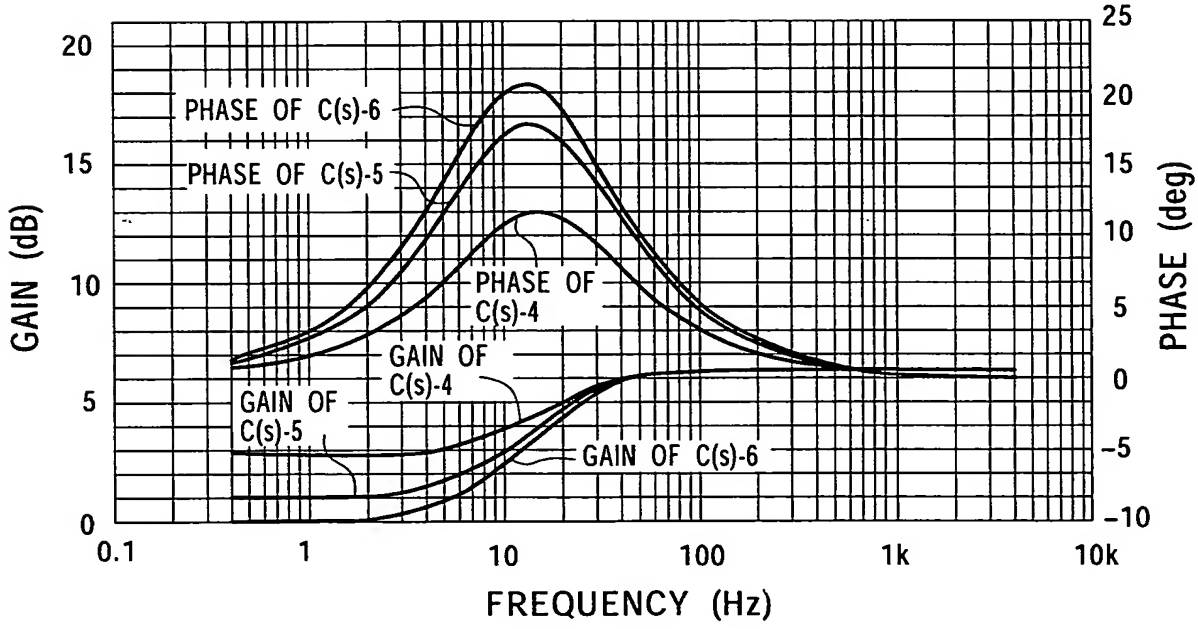

GAIN (dB)
PHASE (deg)
FREQUENCY (Hz)
PHASE OF C(s)-6
PHASE OF C(s)-5
PHASE OF C(s)-4
GAIN OF C(s)-4
GAIN OF C(s)-5
GAIN OF C(s)-6
0.1
1
10
100
1k
10k

FIG. 24

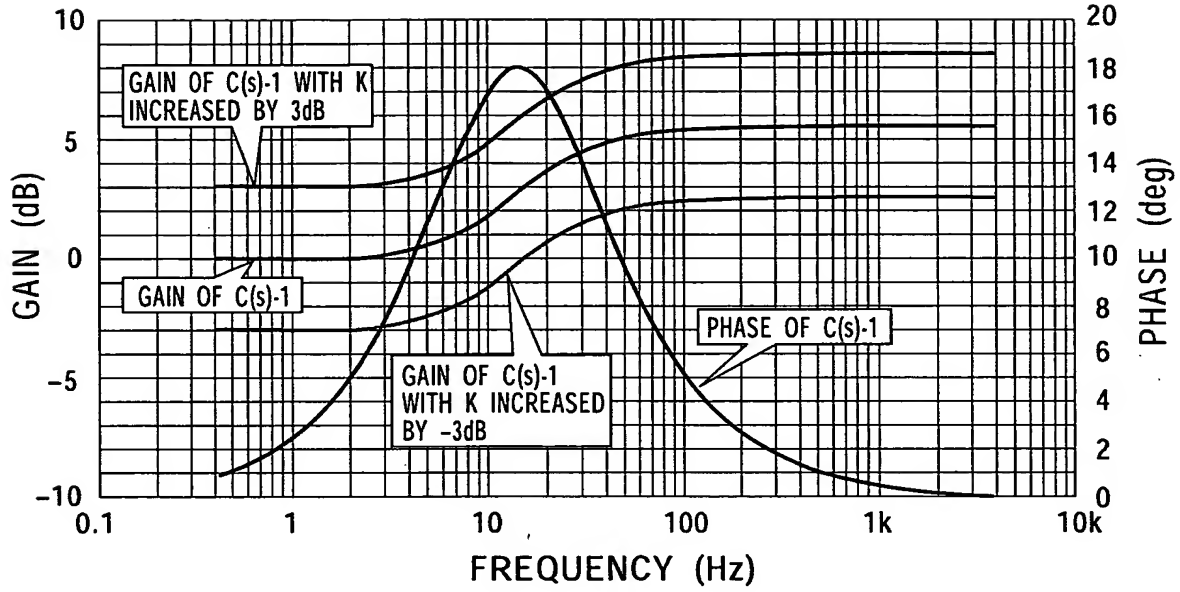

GAIN OF C(s)-1 WITH K INCREASED BY 3dB
GAIN OF C(s)-1
GAIN OF C(s)-1 WITH K INCREASED BY -3dB
PHASE OF C(s)-1
GAIN (dB)
PHASE (deg)
FREQUENCY (Hz)
10
5
0
-5
-10
20
18
16
14
12
10
8
6
4
2
0
0.1
1
10
100
1k
10k

FIG. 25

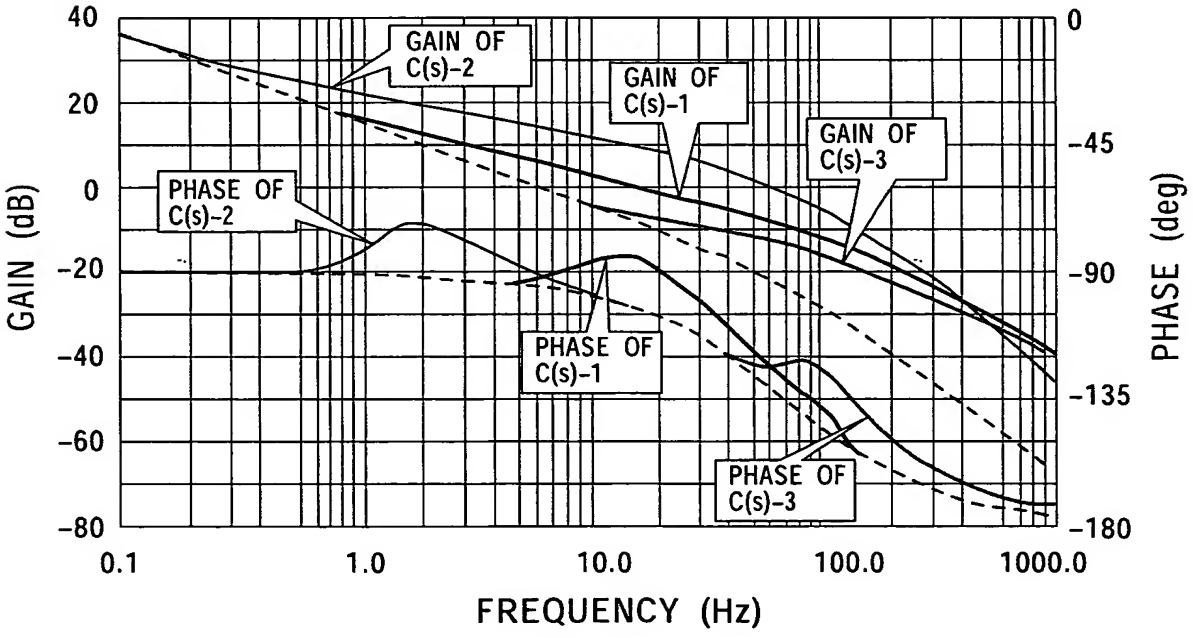

GAIN OF C(s)-2
GAIN OF C(s)-1
GAIN OF C(s)-3
PHASE OF C(s)-2
PHASE OF C(s)-1
PHASE OF C(s)-3
GAIN (dB)
PHASE (deg)
FREQUENCY (Hz)
40
20
0
-20
-40
-60
-80
0
-45
-90
-135
-180
0.1
1.0
10.0
100.0
1000.0

FIG. 26

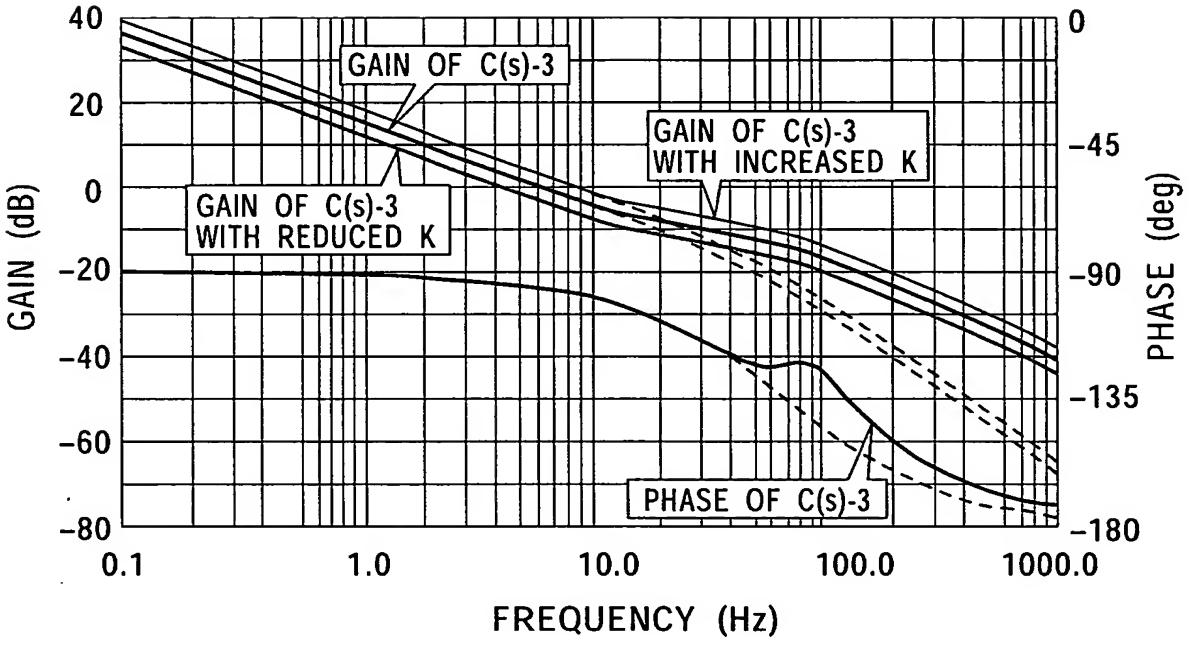
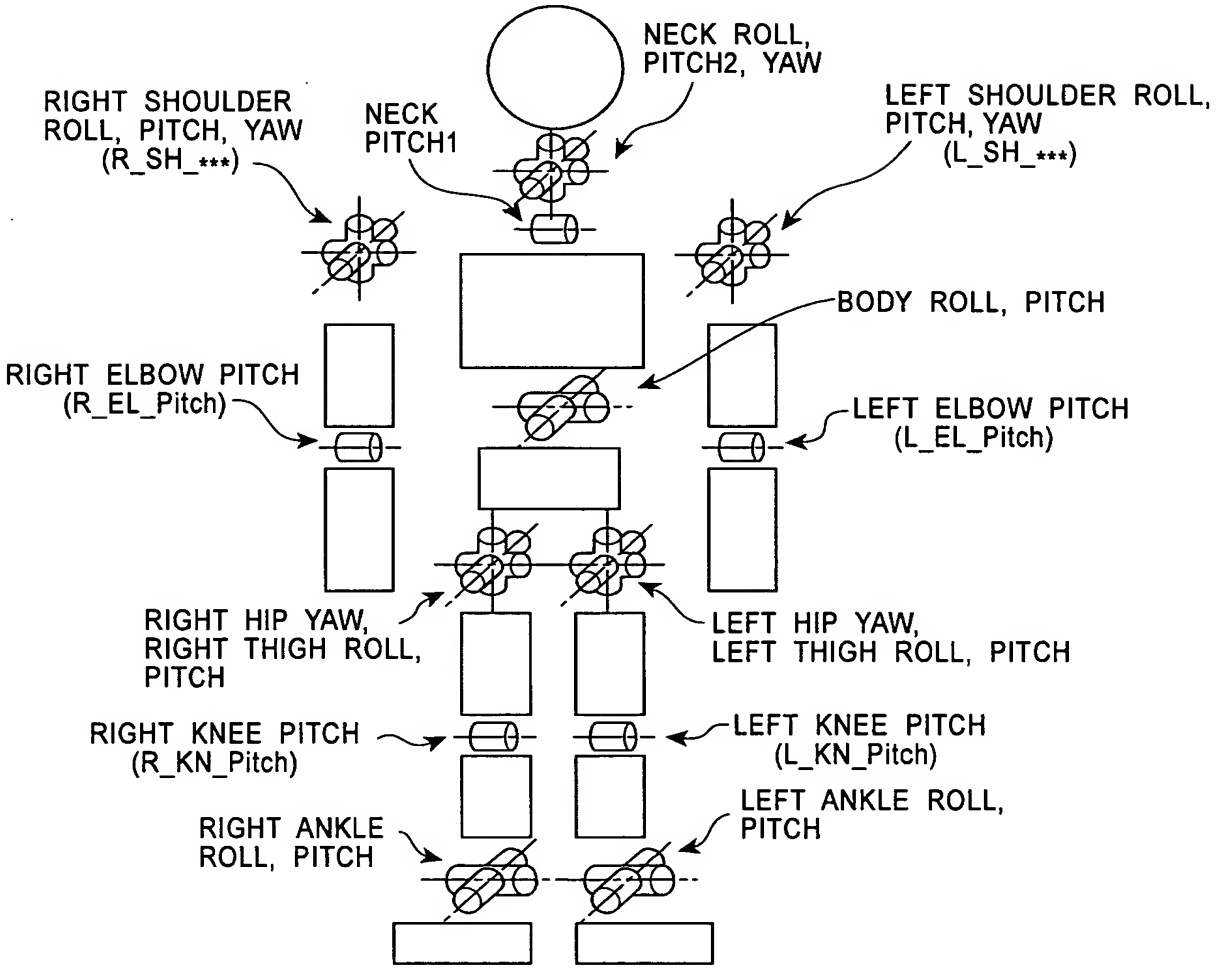

40
20
0
-20
-40
-60
-80
GAIN (dB)
0
-45
-90
-135
-180
PHASE (deg)
0.1
1.0
10.0
100.0
1000.0
FREQUENCY (Hz)
GAIN OF C(s)-3
GAIN OF C(s)-3
WITH INCREASED K
GAIN OF C(s)-3
WITH REDUCED K
PHASE OF C(s)-3

FIG. 27


NECK ROLL, PITCH2, YAW
RIGHT SHOULDER ROLL, PITCH, YAW (R_SH_***)
NECK PITCH1
LEFT SHOULDER ROLL, PITCH, YAW (L_SH_***)
BODY ROLL, PITCH
RIGHT ELBOW PITCH (R_EL_Pitch)
LEFT ELBOW PITCH (L_EL_Pitch)
RIGHT HIP YAW, RIGHT THIGH ROLL, PITCH
LEFT HIP YAW, LEFT THIGH ROLL, PITCH
RIGHT KNEE PITCH (R_KN_Pitch)
LEFT KNEE PITCH (L_KN_Pitch)
RIGHT ANKLE ROLL, PITCH
LEFT ANKLE ROLL, PITCH

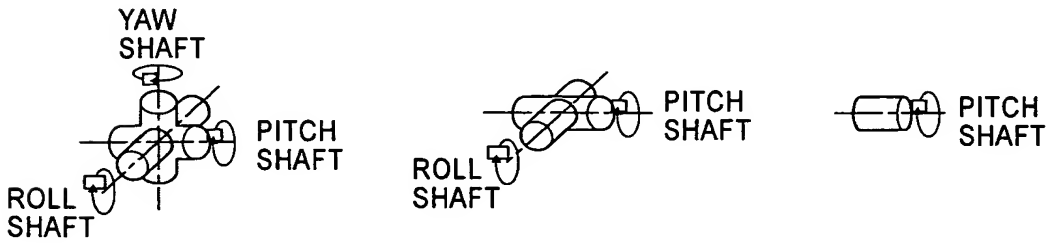

YAW SHAFT
PITCH SHAFT
ROLL SHAFT
PITCH SHAFT
ROLL SHAFT
PITCH SHAFT

FIG. 28

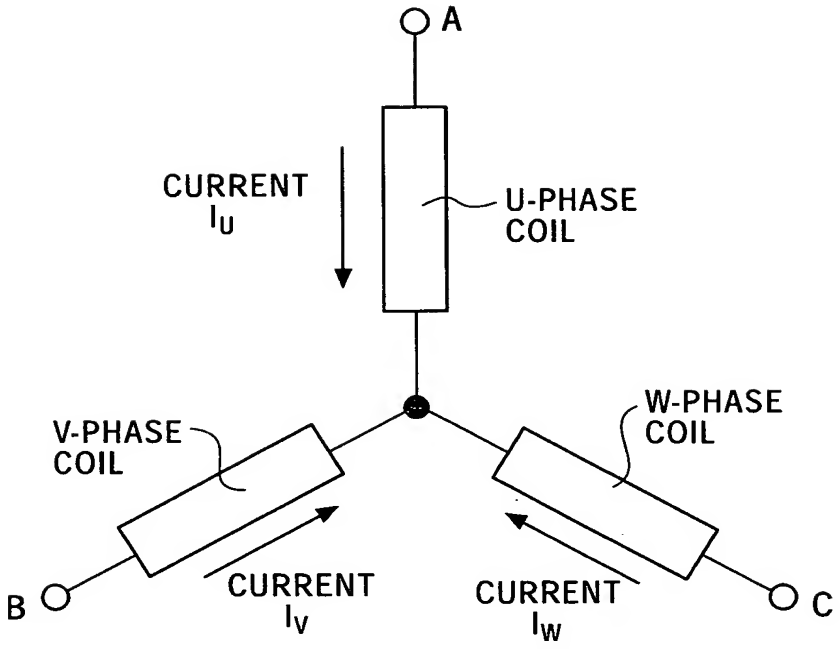

A
CURRENT
I_U
U-PHASE
COIL
V-PHASE
COIL
W-PHASE
COIL
B
CURRENT
I_V
CURRENT
I_W
C

FIG. 29

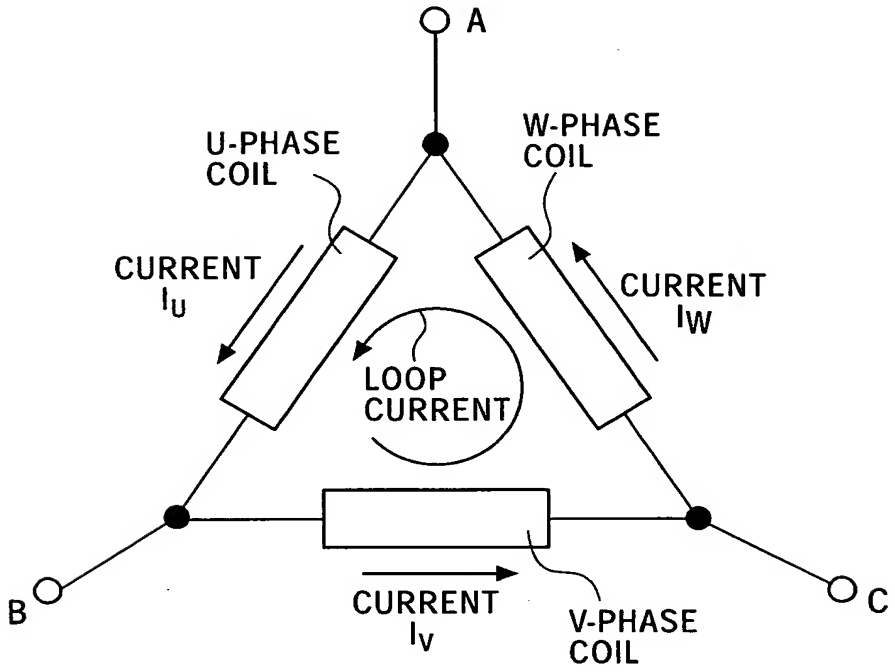
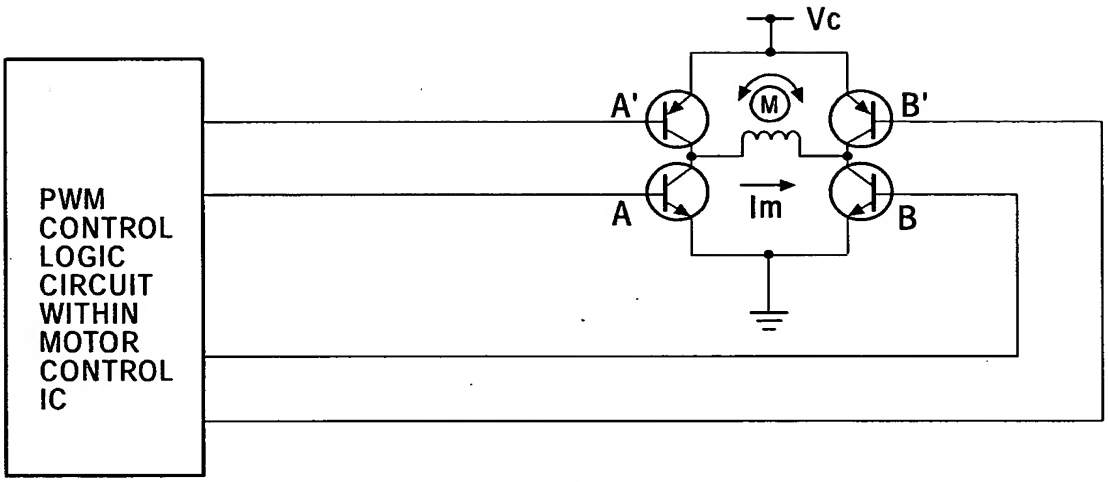

A
U-PHASE COIL
W-PHASE COIL
CURRENT I_U
CURRENT I_W
LOOP CURRENT
B
C
CURRENT I_V
V-PHASE COIL

FIG. 30



Im: CURRENT FLOWING MOTOR COIL (A)
Rm: DC RESISTANCE OF MOTOR COIL (Ω)
Lm: INDUCTANCE OF MOTOR COIL (H)
Vc: POWER SUPPLY VOLTAGE FOR DRIVING MOTOR (V)
Kt: TORQUE COEFFICIENT OF MOTOR (N-m/A)
Ka: COUNTER-ELECTROMOTIVE VOLTAGE COEFFICIENT OF MOTOR (V/rad/s)

FIG. 31

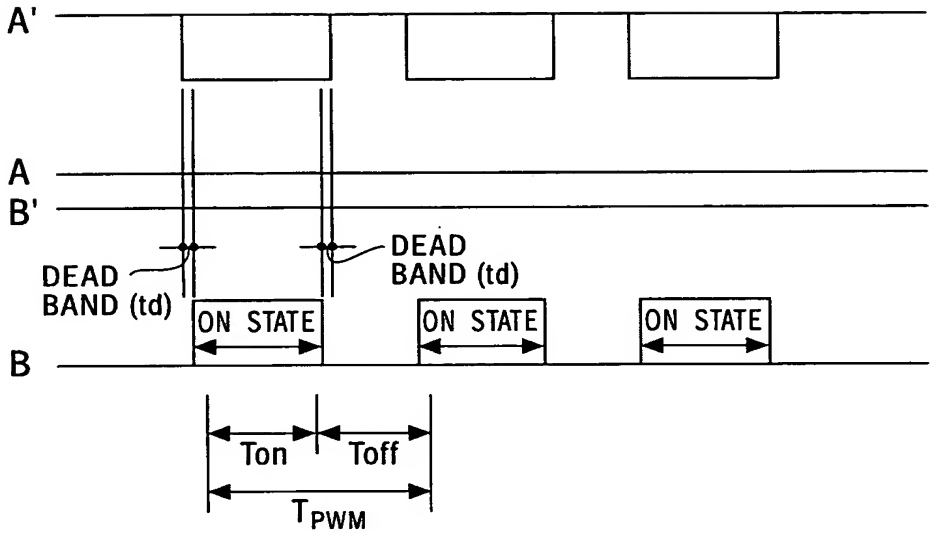

A'
A
B'
DEAD BAND (td)
DEAD BAND (td)
ON STATE
ON STATE
ON STATE
B
Ton
Toff
T_{PWM}

FIG. 32

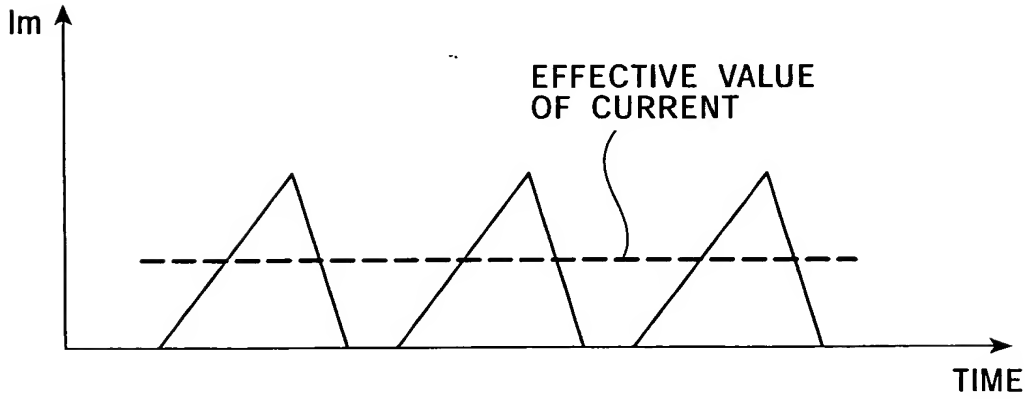

Im
EFFECTIVE VALUE OF CURRENT
TIME

FIG. 33

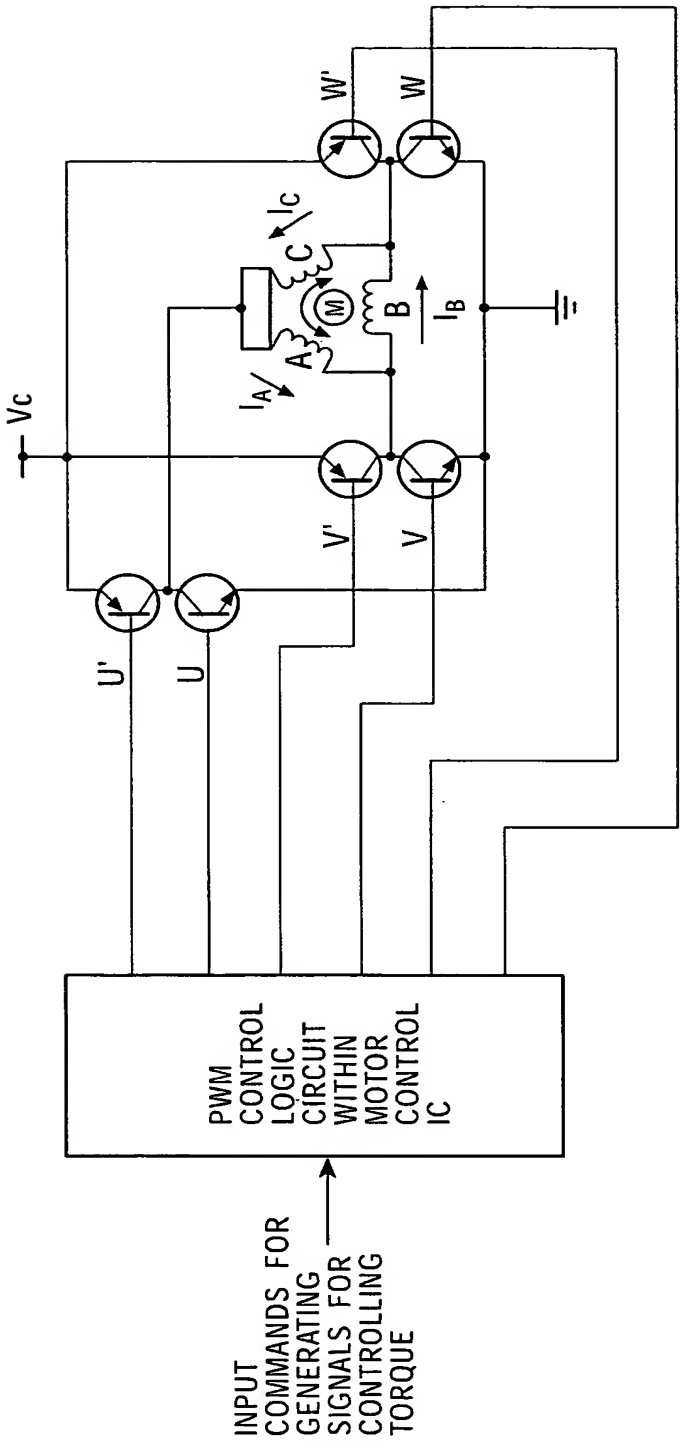
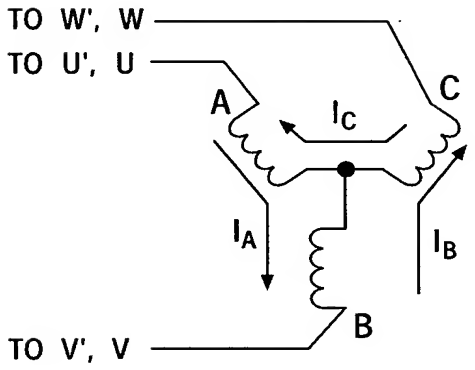

W'
W
Ic
C
M
B
IB
A
IA
Vc
V'
V
U'
U
PWM CONTROL LOGIC CIRCUIT WITHIN MOTOR CONTROL IC
INPUT COMMANDS FOR GENERATING SIGNALS FOR CONTROLLING TORQUE

FIG. 34



$I_A - I_C$: CURRENTS FLOWING A-PHASE MOTOR COIL THROUGH C-PHASE MOTOR COIL (A)

$R_A - R_C$: DC RESISTANCES OF A-PHASE MOTOR COIL THROUGH C-PHASE MOTOR COIL (Ω)

$L_A - L_C$: INDUCTANCES OF A-PHASE MOTOR COIL THROUGH C-PHASE MOTOR COIL (H)

Vc: POWER SUPPLY VOLTAGE FOR DRIVING MOTOR (V)

Kt: TORQUE COEFFICIENT OF MOTOR (N-m/A)

Ka: COUNTER-ELECTROMOTIVE VOLTAGE COEFFICIENT OF MOTOR (V/rad/s)

FIG. 35

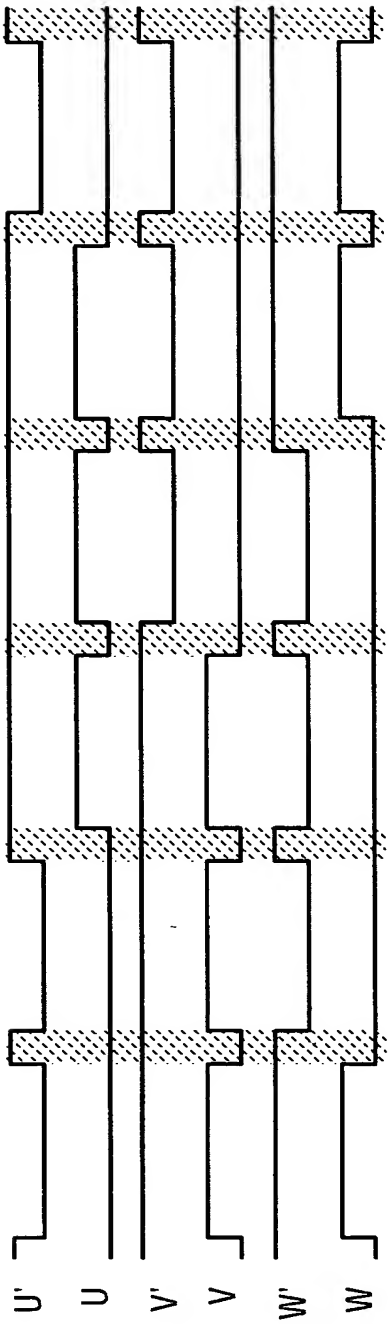


FIG. 36

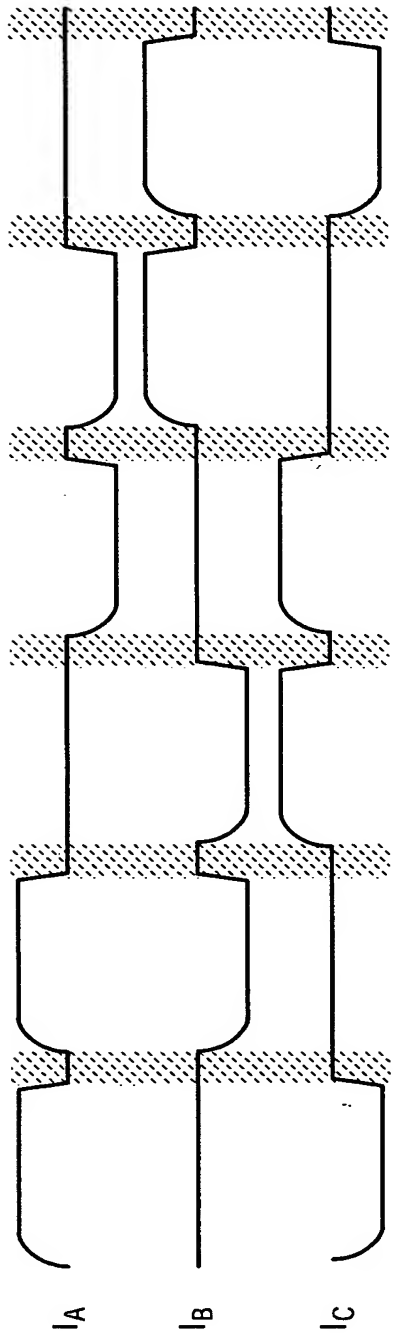


FIG. 37

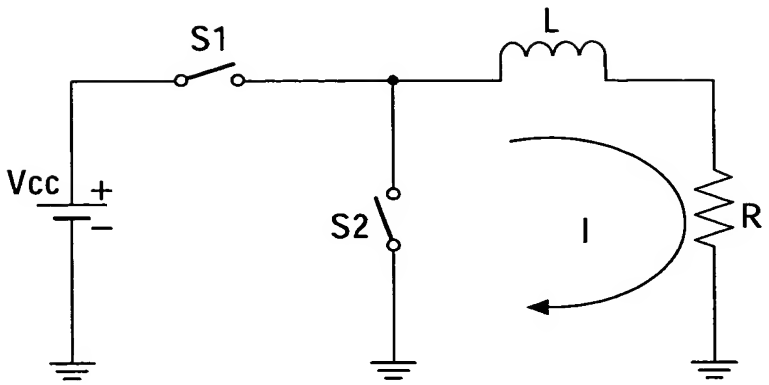


FIG. 38

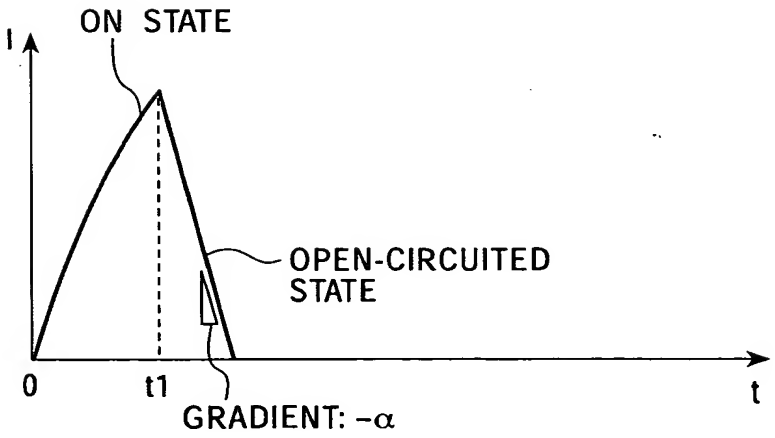
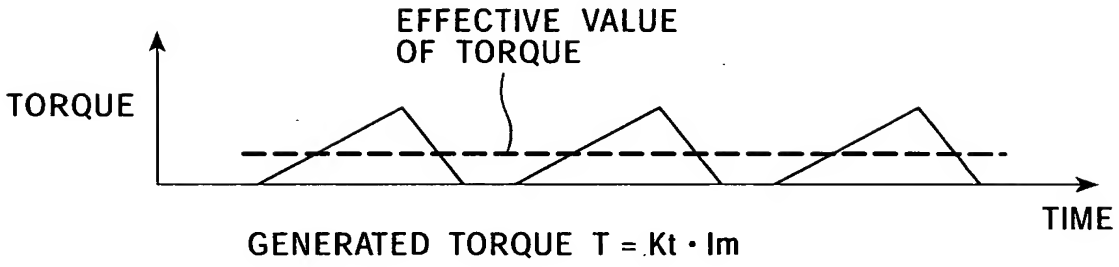


FIG. 39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